ORDER

FEDERAL AVIATION AGENCY

Western-Pacific Region

WP 6000.6

8/8/66

MASTER FILE

SUBJ: MAINTENANCE - NICKEL CADMIUM BATTERIES

1. PURPOSE. This Order provides information to Area Airway Facilities personnel to aid in the understanding and proper use of nickel cadmium batteries.

2. REFERENCE. Sonotone publication, Nickel Cadmium Batteries, by Lewis Hofstatter, Applications Engineer.

3. BACKGROUND.

   a. The present limited use of nickel cadmium batteries in the FAA can be expected to increase in the future.

   b. The generally excellent performance of nickel cadmium batteries, and the proprietary pride of some manufacturers and/or assemblers of equipment using these batteries, has resulted in some misapplication and mishandling of this useful device.

   c. The chief problem is proper charging procedure. The statement is frequently made that nickel cadmium batteries cannot be overcharged, but this is true only when CORRECTLY DESIGNED limited, or trickle, charge devices are used.

   d. Charging methods suitable for lead-acid batteries are entirely inadequate for nickel cadmium batteries without close observation, constant attention, and knowledge of pertinent factors.

   e. There is at present no practical, or readily applied, method by which the existing state of partial charge of a nickel cadmium battery can be determined. Without knowledge of this factor, high rate charging cannot be used for the sealed cells without encountering destructive gassing.

4. DISCUSSION. The subject of nickel cadmium batteries is quite comprehensively covered in the referenced Sonotone publication. Personnel concerned with nickel cadmium battery care and use can benefit from a study of this material. While this is a proprietary article, and minimizes some of the known problems, there is much basic information that can be of great value.

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Initiated by: WP-~~444~~ 460

FAA FORM 2000.1 (2-62)

a. Special attention should be given to the section entitled: Temperature Effects and Charge Retention. The fact of great importance developed here is that the end-of-charge voltage varies inversely with temperature change and can result in thermal runaway. This effect was strikingly demonstrated at several desert sites where vented nickel cadmium batteries were used for engine starting. The conventional lead-acid constant potential system was used for charging. The extremes of temperature made it impossible to find any compromise rate, with the result that the batteries either discharged or boiled violently. It is now known that these batteries could have been used successfully if they had been charged at a constant low trickle rate. The high rate automatic charger should have been used only manually for periodic checks by a technician who could observe the end of charge indication by the start of gassing.

b. The discussions of the C/10 and C/100 rates are particularly pertinent. Assemblers of instruments and equipment are not always conscious of the charging limitations and inadvertently build in rates which may prove to be excessive if used for the time intervals recommended by the instructions for the user; for example, the Alectra 11B DBM/DBA meter.

(1) As originally furnished by the manufacturer, the meter had a charging circuit which forced 40-50 ma. into the 225 ma. battery.

(2) The instructions for charging stated, "It is strongly recommended that it be made standard operating practice to place the battery on charge every night. The battery cannot be damaged by over-charging and the inconvenience of a dead battery will thus automatically be avoided."

(3) Operation under these conditions naturally resulted in early failure of many batteries from rupture of the seals and drying out of the electrolyte. The reason is very apparent since this is a C/5 rate continued for 16 hours every night.

(4) The charging rate was subsequently corrected to a C/10 rate by modification instructions in AF P 6500.1, CH 17, Chapter 103. However, even with this reduced rate it should be apparent that the battery cannot be charged "every night" unless it has been used all day at its normal discharge of about 20 ma. The 140% charge rule discussed in the reference should be conformed to as nearly as is possible and practical.

c. The cell reversal discussion will also be enlightening to those technicians who have had batteries fail after overdischarge.

5. ACTION. Technicians responsible for maintenance of equipment which utilizes nickel cadmium batteries shall consider the referenced information and determine that the charging rates and/or charging times are appropriate for the capacity and type of battery. Where discrepancies are found, between manual operating instructions and the practical limitations of the battery, data shall be provided to support recommendations for changes to equipment or operating methods.

APPROVED WESTERN REGION AUGUST 8, 1966

MASTER FILE

Nickel-Cadmium Batteries

By LEWIS HOFSTÄTTER / Applications Engineer, Battery Div., Sonotone Corp.

This truly rechargeable and compact power source has led to the development of a wide variety of cordless devices in consumer, commercial, industrial, and military areas.

ONE of the most significant developments in portable power during the past 25 years has been the refinement and mass production of nickel-cadmium alkaline batteries. Many millions of sealed and vented rechargeable cells have been used successfully in a wide variety of consumer, commercial, industrial, and military applications. Whole families of new cordless products have come into being, based chiefly on the high performance capabilities of the sealed nickel-cadmium system. The market for the truly rechargeable battery continues to have a brilliant future and, until the fuel cell becomes economically practical, it seems likely that the greatest hope for reliable portable rechargeable power will lie with the nickel-cadmium battery system.

Pocket-Plate Nickel-Cadmium

The first rechargeable alkaline battery was developed by Waldemar Jungner of Sweden in 1899 and employed an open pocket-plate type of cell.

The pocket plate (Fig. 1, left) is a flat nickel-plated steel structure containing parallel rows of small pockets or chambers to hold the active materials. These pockets are very finely perforated to allow electrolyte access without permitting the escape of the material inside. Polystyrene or glass rods are used as separators between plates immersed in aqueous potassium hydroxide electrolyte. The positive plates contain nickel salts and the negative plates contain cadmium salts.

The vented pocket-plate nickel-cadmium battery has proven to be the heavy-duty work horse of the industry. Available in capacities from 10 to about 2000 ampere-hours, the cells may be encased in either plastic or steel. They are assembled in hardwood trays of convenient size and these can then be tiered in steel racks. Each cell delivers 1.2 volts and the most common voltage units are 6, 12, 24, 32, 48, 110, and 220, but any intermediate value can also be obtained.

These batteries have an extremely low internal resistance and can thus deliver very high currents with little loss of voltage. Conversely, they can also be recharged at greatly accelerated rates and, at normal temperatures, will hold their charge for very long periods. When delivering moderate currents, they will perform satisfactorily even at temperatures of −40°C.

Pocket-plate vented cells utilize an excess amount of alkaline electrolyte and contain vents through which evolved gases are released and additional water or electrolyte may be added, if required, for proper maintenance. They are not the lightest batteries in the world, but they probably are the most reliable, often providing as much as 25 years' of useful service. These batteries are thus employed in emergency standby applications with marine, lighting, alarm, control signaling, switchgear, telephone, engine starting, as well as for auxiliary utility power systems.

Sealed Sintered-Plate Nickel-Cadmium

The sintered-plate type of nickel-cadmium cell was developed in Germany during the Second World War and was produced in this country shortly after the war ended. The greatest current activity and volume in nickel-cadmium batteries is with the sealed sintered-plate types. The best testimonial to the efficiency, reliability, and complete lack of maintenance in sealed nickel-cadmium cells is the fact that probably more than half the consumers using cordless appliances with such batteries do not even realize that they contain batteries at all. Many manufacturers have encouraged this tendency by referring to the power source as an "energy cell" or a "powerpack," because they feel that there may otherwise be some sales resistance to a battery-powered device.

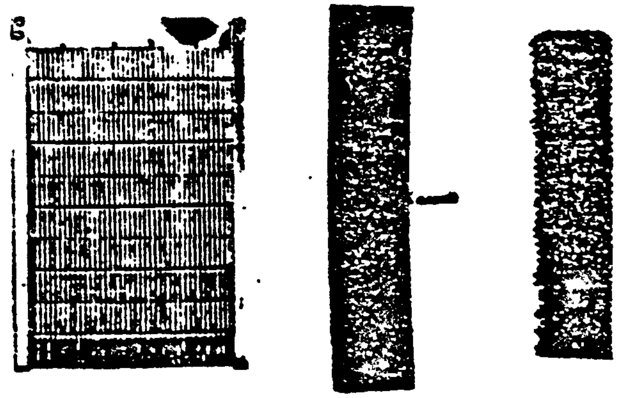
The sealed sintered-plate cell has five main components: a positive plate, a separator or dielectric, a negative plate, electrolyte, and a container. (See cover illustration.) No access vent is provided in a sealed cell and a limited quantity of electrolyte is used, thus reducing maintenance to a minimum and eliminating the need to add either water or electrolyte.

Preparation of positive or negative plates requires the sintering of a fine nickel powder to a woven nickel wire screen. (Sintering involves the conversion of a powdered or earthy substance into a coherent solid mass by heating without thoroughly melting.) This not only acts as a matrix conductor, but also imparts great strength and flexibility to the plate. This results in a thin, highly porous nickel plaque (Fig. 1, center) which is then impregnated with nickel salt solutions for the positive plate and cadmium salt solutions for the negative plate.

The separator, an absorbent dielectric material, mechanically separates the positive plate from the negative while holding electrolyte and permitting ions or electrical current to flow between the plates. The electrolyte used is an aqueous solution of potassium hydroxide.

The usual cell container is a nickel-plated steel can and cover. The cell is assembled by rolling both plates, separated by the dielectric, into a tight roll or core which is then

Fig. 1. Three typical nickel-cadmium battery plates. From left, modern pocket plate, sintered plate, and pasted plate.



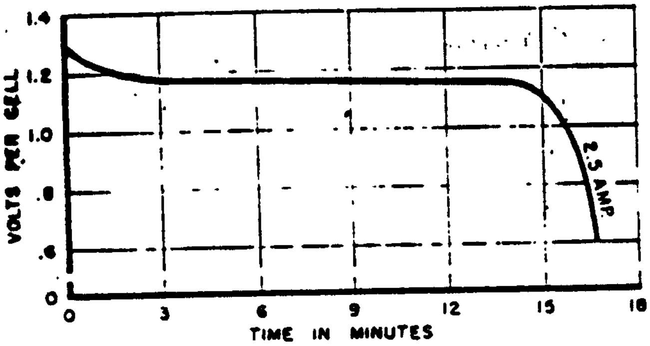


Fig. 2. Cell-discharge voltage vs time for a type S102 cell. This is one-half the size of a standard "C" cell.

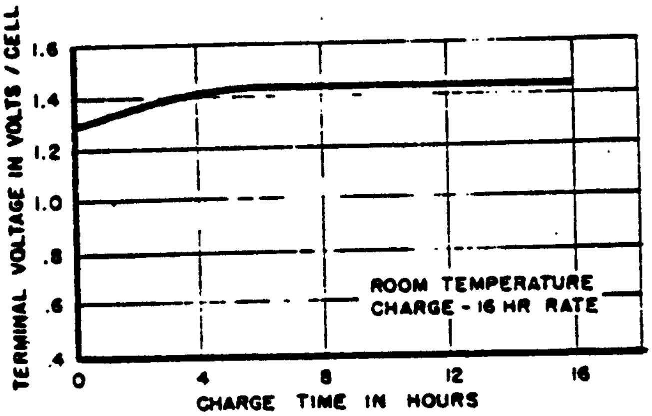


Fig. 3. Terminal voltage measured during a constant charge.

placed into the can with the electrolyte and sealed. The negative plate tab is welded to the bottom of the can, making the entire cell case the negative terminal. The entire cell assembly is then charged, discharged, and completely inspected by the manufacturer of the cell.

Electrical Characteristics

The *closed-circuit voltage* of a single nickel-cadmium cell, irrespective of size or shape, is nominally 1.25 volts but certain other voltage levels may also be encountered.

Open-circuit voltage is the voltage of a cell without a load. At room temperature, this is 1.33 volts. This represents the normal terminal voltage of a nickel-cadmium electrode pair immersed in potassium hydroxide electrolyte.

End-of-discharge voltage is the final voltage to which a cell is discharged. Levels below 1.0 volt per cell should be avoided where possible. Quite often, a higher end point can be used because most of the cell's capacity is exhausted at voltage levels somewhere between 1.10 volts and 1.15 volts (Fig. 2).

End-of-charge voltage is the final voltage across the cell at the end of charge, with charge current still flowing through it. A cell placed on constant charge soon rises to a voltage of 1.40 (Fig. 3) and can climb to 1.47 volts or more. 1.43 volts is an average final voltage and a cell is questionable if it does not reflect voltages reasonably close to these.

Ampere-hour capacity is generally measured to a 1.0-volt per cell end-point and is the product of discharge current and the time under load.

Capacity varies with the discharge rate. Figs. 4 and 5 indicate that at a 1-hour rate the cells will yield about 80% of their 5-hour rate, which is considered the standard capacity of the cell. At lower rates, such as the 10- or 20-hour rate, a somewhat higher capacity than that of the 5-hour rate is obtained. To illustrate, the "AA" size (ordinary penlight) sintered-plate cell has a nominal capacity of 510 ma.hrs. at the 5-hour rate of discharge, 430 ma.hrs. at the 1-hour discharge rate, and 550 ma.hrs. at the 20-hour rate. Fig. 4 also indicates what may be expected in voltage level on any size cell if the discharge rate is changed from the 5-hour to the 10-minute or 1-hour rate.

High-current capability. Sealed sintered-plate cells can deliver high current discharges in the neighborhood of 10 to 15 times their 5-hour rated capacity. For example, a "½ C" cell with a capacity of 800 ma.hrs. may be used to deliver 10 amperes for a short time. The same cell will provide a full 16 minutes of operation at a constant discharge of 2.5 amperes (see Fig. 6A). Ordinary batteries are ruined by such treatment. Fig. 4 shows the effect of discharge current upon actual cell capacity obtainable. Note that the total energy available (the area under the curves) is somewhat lower at high current drains, but that the voltage regulation is still excellent.

Table 1 lists representative data on a few of the more popular types of sealed nickel-cadmium cells.

Temperature Effects & Charge Retention

While their discharge performance is affected somewhat at temperature extremes, sealed, sintered-plate nickel-cadmium cells offer some advantages over other battery systems in this respect. At 32°F, the cells will yield approximately 90% of their room temperature capacity, while at 125°F they will produce 70%. The cells can also supply useful but reduced energy over the range of −40° to +165°F. Discharge voltage levels will decrease somewhat from those encountered at room temperatures as the temperature is either increased or decreased.

For best results, cells should be charged at ambient temperatures between 60° and 100°F. End-of-charge voltages can be expected to be higher (1.55 volts) than those encountered at room temperatures when cells are charged at cold temperatures and can be expected to be lower (1.37 volts) at the upper extreme temperatures. This is why sealed cells should never be charged by constant potential, since the cells tend to warm up during charge and thus de-

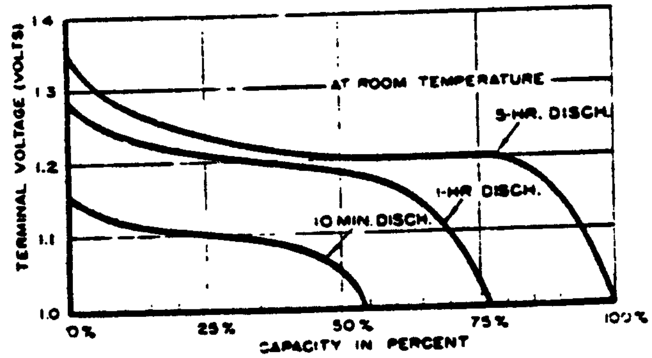
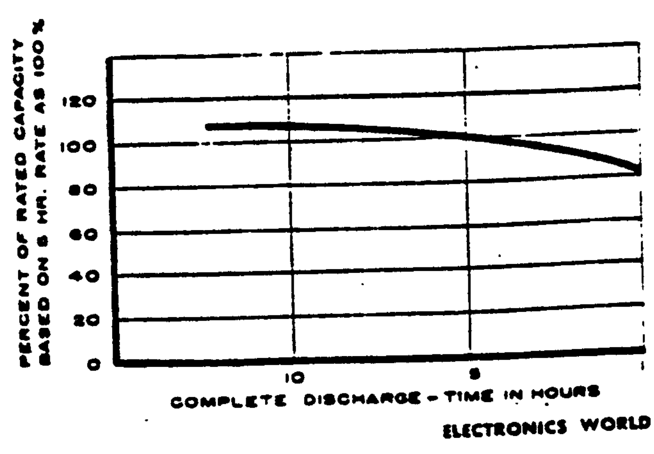


Fig. 4. Discharge voltage characteristics of cylindrical sealed cells for a number of different rates of discharge.

Fig. 5. The variation of cell capacity with discharge rate.



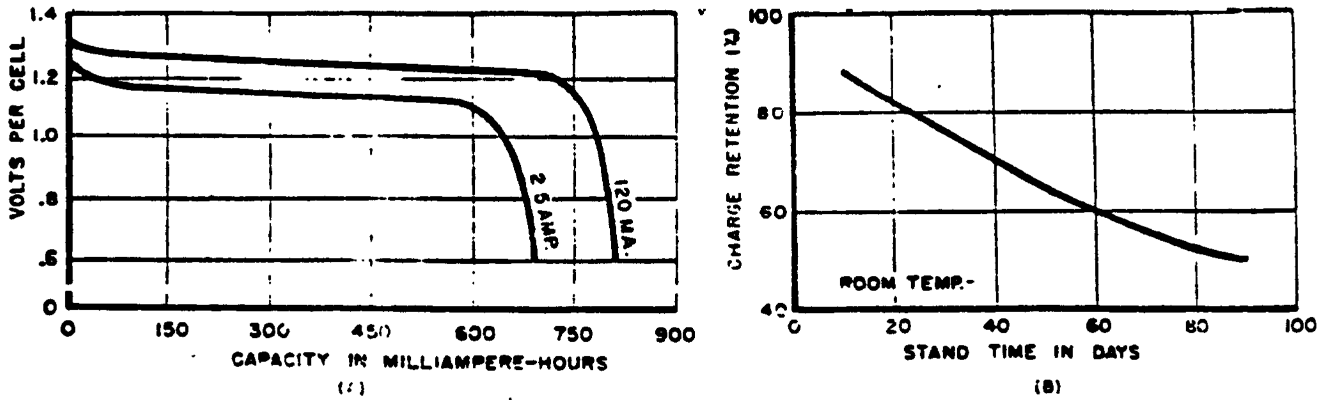


Fig. 6. (A) Comparison between capacities of "½C" size for two discharge rates. Note 600-ma. hr. capacity at 2.5-amp. discharge. (B) Charge-retention characteristics of nickel-cadmium cell.

crease in voltage. The charger will then simply increased currents, causing more heating, and so on, until cell failure results. This condition is call "thermal runaway," and can be prevented only by using constant-current charging.

The sealed nickel-cadmium cell, like all electrochemical storage devices, loses a percentage of its charge while in storage. At room temperature, the cell will retain 75% of its capacity after a 30-day stand, 60% after 60 days, and 50% of its capacity after a 90-day period (Fig. 6B). In any case, the loss of charge is only of a temporary nature and can be regained on subsequent charging. One of the advantages of a rechargeable system is that the loss of shelf life can be prevented by keeping the cells on a trickle charge or simply by recharging them before being placed into service.

Cell Reversal

If a multiple-cell battery is deeply discharged at currents much greater than $C/10$ (C = amp. hr. capacity of cell at 5-hr. rate), there is a possibility that cell reversal will occur. This can happen if one cell is slightly lower in capacity than the others and if, during discharge, its voltage falls near zero while the other cells may be at one volt or more. The battery will continue to discharge through the "dead" cell, charging it in reverse, as it were. If the discharge continues long enough, the cell may reverse its polarity and be damaged.

It occasionally becomes necessary to protect a sealed nickel-cadmium battery from the repetitive deep discharges that might prove injurious. In some cases, the device can be designed to become inoperative when the voltage drops below 1 volt per cell. At other times, the user can be instructed to charge whenever the power appears to weaken. One solution is to use the appropriate zener diode across each cell to prevent it from being driven into reverse polarity. When the weakest cell reaches a reverse 0.1 volt, the diode will pass all the current instead of the cell, thus preventing damage. The correct zener diode must be able to begin conducting current at very low voltages and must possess the required current-handling capability. Such diodes are often quite expensive, so simpler techniques are generally employed. These usually involve the use of a relay across the battery terminals which disconnects the load when terminal voltage drops to a predetermined value.

State of Charge

The state of charge is the amount of energy left in a battery at any given time. There is no simple, practical way of measuring the state of charge in a nickel-cadmium system, since the voltage does not reflect residual capacity and the electrolyte serves chiefly as an ion-carrier, without significant changes in its specific gravity. When dealing with either vented or sealed nickel-cadmium batteries, if in doubt about the state of charge, the best procedure is simply to give a 14-hour freshening charge at the $C/10$ rate or keep on trickle charge permanently at $C/100$.

Charging Techniques

Recharging sealed cells is a simple matter and can be accomplished in several ways. In each case, only constant-current charging should be used due to the possibility of "thermal runaway," described earlier. Because there are some heat losses, gas evolution, and side reactions, recharging is never 100% efficient and it is necessary to replace 140% of what was removed. The standard recharge rate is at a current value of 1/10 the cell capacity ($C/10$) for from 14 to 16 hours.

Fig. 7A shows a typical half-wave constant-current charger. Note that no filtering is required for nickel-cadmium chargers, since the average cell has an enormous equivalent capacitance. The charger is actually a current-limited device and will not really provide a truly "constant" current, since the counter-e.m.f. of the battery rises during charge and will oppose the transformer e.m.f. The charge currents will be quite constant enough, however, for battery charging and no trouble will be encountered if the current at the end of the charge does not exceed the $C/10$ rate for sintered-plate batteries.

The value of R is chosen as follows:

1. Multiply the number of cells by 1.45 volts to obtain the counter-e.m.f. at end-of-charge.
2. Select transformer with a secondary voltage that is at least twice this voltage.

Table 1. Characteristics of sealed cells. "AA" cells are penlight type while "D" cells are standard flashlight type.

Size	Average Capacity (5-hr. rate)	Average Capacity (1-hr. rate)	Charge for 14-hours (constant current)	Dia. (in.)	Over-all Hgt. (in.)	Weight (oz.)	60-cps Impedance (in milliohms)
AA	.51 amp. hr.	.43 amp. hr.	50 ma.	.580	1.985	0.8	22
C	1.9	1.6	150	1.022	1.925	2.6	15
D	4.0	3.2	400	1.333	2.385	5.5	12
F	6.5	6.0	600	1.333	3.455	8.3	7

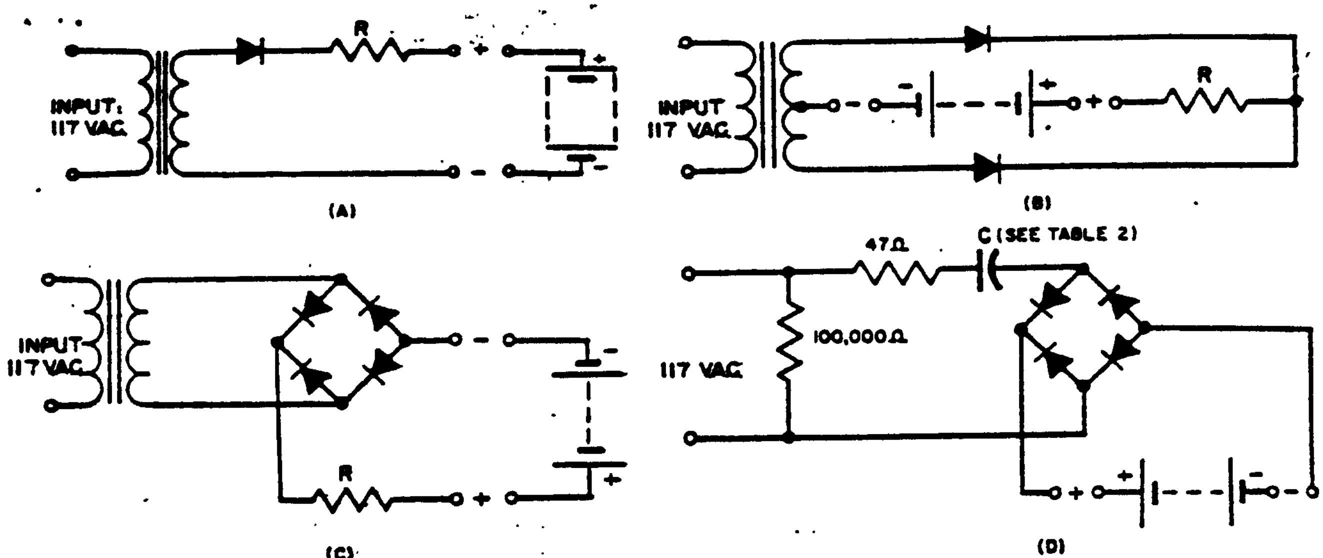


Fig. 7. A grouping of nearly constant current charging circuits recommended for nickel-cadmium cells.

3. Subtract voltage from step (1) from voltage of step (2).

4. Use this value for E in the formula $R=E/I$; use $C/10$ current (or the current desired) for the value of I, and solve for R. The wattage rating of the resistor should be 2.5 to 3 times the product of E and I. Adjustable resistors are handy for prototype use, because exact settings can be made.

The diode should have a conservative peak inverse voltage rating. It will run cool if capable of handling twice the maximum anticipated current. Remember that a heavily discharged battery will draw substantially higher currents until its counter-e.m.f. rises. Some manufacturers incorporate the ballast resistor in the secondary winding of the transformer, others use an incandescent pilot light as a combination resistor, fuse, and charge-rate indicator.

At higher currents and for greater efficiency, full-wave charging can be used. If the transformer secondary is center-tapped, the double-diode circuit of Fig. 7B can be used. The value for R is calculated as above, but the secondary voltage of the transformer is just twice that required for half-wave rectification.

A common full-wave charger using an untapped secondary and a bridge rectifier is shown in Fig. 7C. The bridge rectifier requires four diodes and must not be operated without the battery connected, because the resulting current imbalance could damage the diodes. The same bridge can be used with a capacitor replacing the transformer, as in Fig. 7D. Due to the size of the capacitor, it is feasible only for small or moderate currents. Table 2 shows some typical values for C at various charge rates.

Table 2. Values for series capacitor C in Fig. 7D. This particular circuit has a potential shock hazard as it is connected directly to the power line, hence it should be built into end device with suitable personnel protection.

Cell Capacity (ma.hr.)	Number of Cells in Series	Value of C (in μf.)	Nominal Charging Current (ma.)
50	1 to 5	0.12	5
100	1 to 5	0.25	10
150	1 to 5	0.40	15
250	1 to 5	0.65	25
500	1 to 5	1.40	50
1000	1 to 5	3.25	100

Smaller cells can sometimes be conveniently recharged from a larger primary battery—the relative voltages often work out perfectly. For example, a pair of 20 ma.hr. hearing-aid cells can be recharged in parallel from a single #6 Leclanché cell. These cells may be kept on charge while another pair of cells is used in the hearing aid. At least two years of use can be obtained in this manner.

Most sintered-plate sealed cells made today have some sort of safety venting device to prevent seal failure in the event of cell abuse. A puncturable diaphragm composes the top cell seal and a piercing point impinges upon the center of the diaphragm. Any gas accumulation due to excessive discharging or charging rates will cause the diaphragm to be distended upward and the point will make a small puncture. When the gas pressure is relieved by venting to the external atmosphere through the hole in the top cover, the diaphragm is elastically restored to its original plane, almost closing the pierced opening. The cell will continue to function for a number of cycles but it will naturally age somewhat faster than would an unpunctured cell.

Cycle Life & Packaging

Cycle life refers to the number of charge-discharge cycles of operation possible before capacity drops to a predetermined level. Cycle life is at an optimum when overdischarge is avoided, recharging is performed regularly, and depth-of-discharge is kept as shallow as possible. When the charge-discharge cycles are nearly full, life is measurable in hundreds of such cycles: when partial discharges are used, cycle life may be in the thousands.

Sealed cells are available in capacities from 20 ma.hrs. to 25 ampere-hours and they can all be assembled to form a variety of finished battery packs. Small disc cells are stacked to make compact cylindrical batteries. The popular cylindrical cells may be packaged either in long end-to-end cylinders or side-by-side in convenient modular configuration; larger rectangular cells are assembled side-by-side in battery trays or enclosures.

Pasted or Pressed Plate

For many years, nickel-cadmium cells have been made by simply pressing, under pressure, a paste of active materials into a supporting matrix (Fig. 1, right) rather than by sintering. This type of cell is less expensive to produce, has excellent charge retention, and gives good capacity-volume efficiency. However, it has a higher internal resistance and is thus limited to low and moderate current-drain applications. Pasted-plate cells are available in both cylindrical and disc-shaped configurations; the latter can be assembled

MASTER FILE WP 6000.6

in stacks to give any desired voltage. These cells are relatively inexpensive compared to the sintered-plate type and have a minimum average life of from one to three years.

Vented Sintered-Plate Batteries

Vented cells are produced from standard sintered plates which are made in parallel assemblies to give a rectangular configuration (Fig. 8). Batteries of these cells can safely deliver enormous currents with good voltage regulation. They may be fully charged in times as short as ½ hour over temperatures from −65° to +165°F. The cell containers are polystyrene or nylon and are housed in stainless steel or fiberglass battery cases. No acids, noxious gases, or corrosive fumes are evolved during normal use. Because of the type of one-way vent employed, these cells can be discharged in any position, although they should be kept vertical during fast discharge to prevent loss of electrolyte. Vented sintered-plate batteries can be stored for long periods in any state of charge and will retain a charge for at least a year.

The extremely long life and corrosion-resistant construction virtually eliminates the need for inspection or maintenance. An occasional electrolyte check and the addition of a little distilled water a couple of times a year is all that may be required. If it ever becomes necessary to change a vented cell in a battery, the cell is simply removed and replaced by a new one. This feature enables every battery cell to be used to exhaustion. Because all the internal connections are welded and the plates have very low resistance, pulse discharges up to 40 times the cell capacity are possible.

The vented sintered-plate nickel-cadmium batteries are extensively used in military and industrial applications, including engine starting, switchgear operation, and emergency standby service. Available in low-, medium-, and high-current rate versions, they are more expensive than their sealed counterparts but have a normal life expectancy of from 5 to 10 years. Vented cells may be charged with either constant voltage or constant current, whichever seems more suitable. Combination circuits can be designed to charge initially at constant voltage and high current, then taper automatically to constant trickle current.

At times it may be necessary to charge two or more cells in parallel. This can be accomplished by inserting a resistor in series with each of the cells being charged from a single source. The value of the resistor chosen must be at least 100 times the magnitude of the internal resistance of each cell. Slight differences in cell internal resistance thus exert a negligible effect. ▲

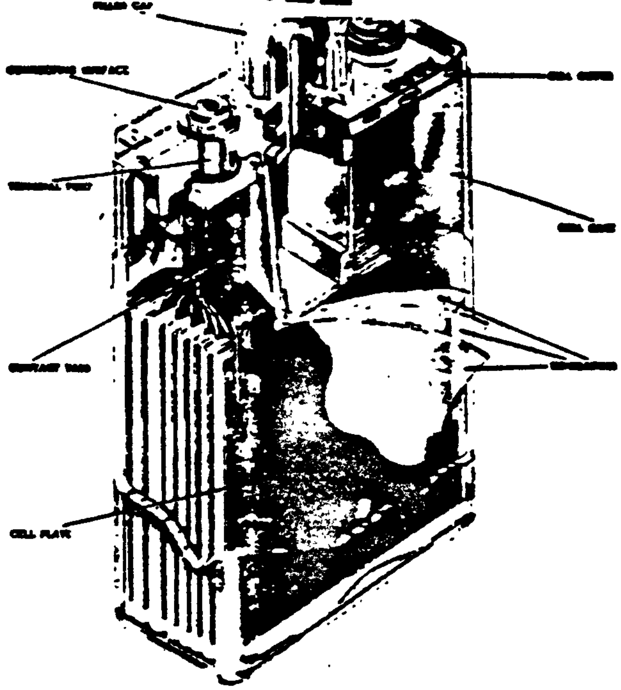


Fig. 8. Cutaway view of vented sintered-plate battery cell.

Battery Sources

Mercury	Silver-Zinc	Carbon-Zinc	Silver-Cadmium	Nickel-Cadmium	Alkaline-Manganese	
		●				Acme Battery Corp., 200 Henry St., Stamford, Conn.
				●		Alkaline Batteries Co., 2278 Mora Dr., Mountain View, Cal.
		●		●		Bright Star Industries, 600 Getty Ave., Clifton, N. J.
●	●	●		●	●	Burgess Battery Co., Freeport, Illinois
		●				Carbone Corp., 400 Myrtle Ave., Boonton, N. J.
	●	●		●		Catalyst Research Corp., 6101 Falls Road, Baltimore 9, Md.
	●					Cook Batteries Co., Denver, Colorado
	●					Delco-Remy Div., General Motors Corp., Anderson, Indiana
	●		●	●		Eagle-Picher Co. Chemicals Div., P.O.B. 290, Joplin, Mo.
●	●	●	●	●	●	Electric Storage Battery Co., 2 Penn Center Plaza, Philadelphia, Pa.
	●		●	●		Electrochimica Corp., 1140 O'Brien Dr., Melno Park, Cal.
	●		●	●		General Electric Co., Battery Prod. Sect., P.O.B. 114, Gainesville, Florida
	●					General Electric Co., Ordnance Dept., 100 Plastics Ave., Pittsfield, Mass.
	●		●	●		Gould-National Batteries Inc., Alkaline Battery Div., 1st Nat. Bank Bldg., St. Paul, Minn.
			●	●		Gulton Industries Inc., 212 Durham Ave., Metuchen, N. J.
●	●	●			●	Mallory Battery Co., Broadway & Sunnyside Lane, Tarrytown, N.Y.
		●				Marathon Battery Co., Box 298, Wausau, Wisconsin
				●		Nife Inc., Copiague, Long Island, N. Y.
●		●			●	RCA, Electronics Components and Devices, 415 S. Fifth St., Harrison, N. J.
				●		Sonotone Corp., Battery Div., Saw Mill River Rd., Elmsford, N. Y.
	●		●			Telecomputing Corp., Power Sources Div., 3850 Olive St., Denver, Colorado
●		●		●	●	Union Carbide Corp., Eveready, 270 Park Ave., New York 17, N. Y.*
	●		●			Yardney Electric Co., 40 Leonard St., New York 13, N. Y.

*Also makes air-depolarized types.